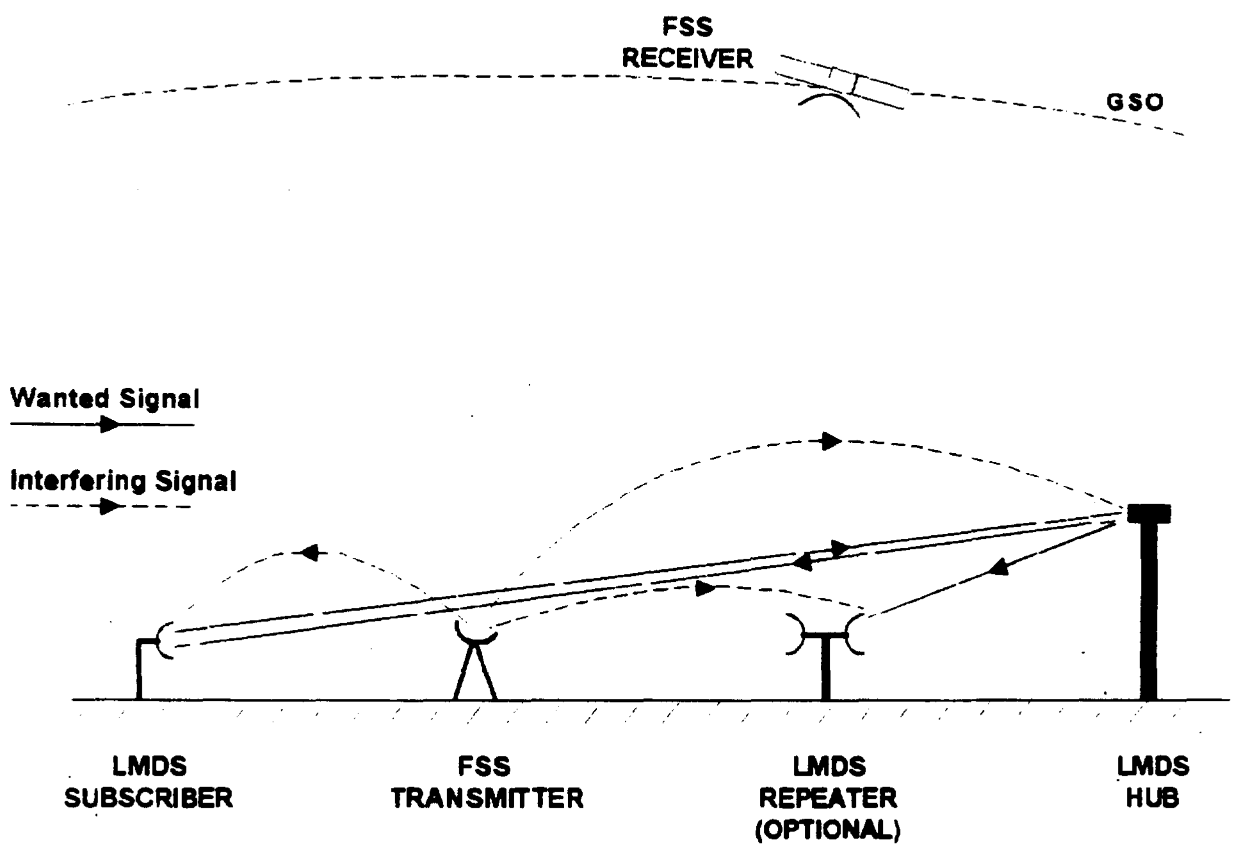

Figure 3.1-1 FSS Terminal Accessing GSO Satellite Sending Interfering Signals Towards Receivers in an LMDS System. (Hub, Subscriber, and Repeater Receivers Shown)

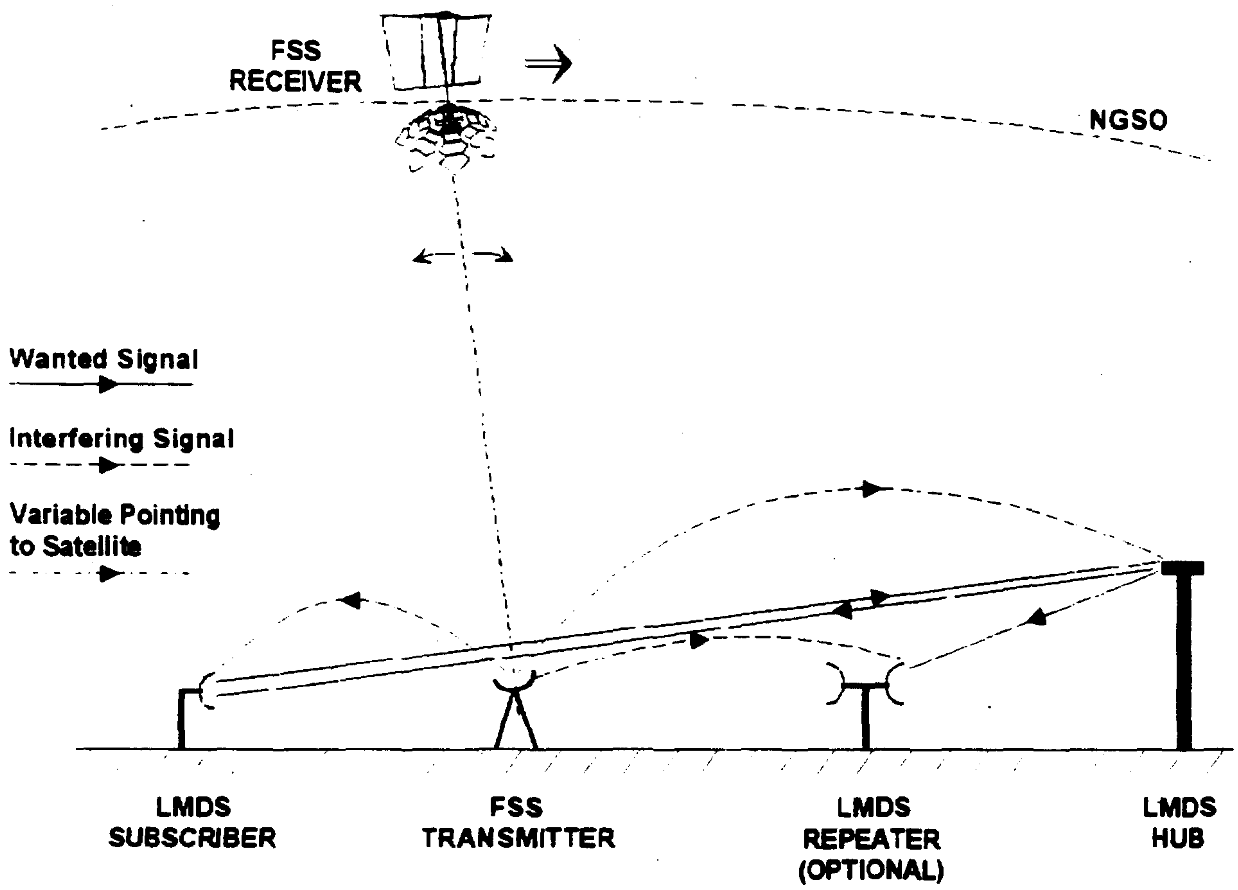

Figure 3.2-1 FSS Terminal Accessing NGSO Satellites Sending Interfering Signals Towards Receivers in an LMDS System. (Hub, Subscriber, and Repeater Receivers Shown)

3.3 LMDS Transmitters Interfering into GSO FSS Satellite Receivers

The model for this scenario is shown in Figure 3.3-1. Each of three or more types of LMDS transmitters sends potentially interfering signals towards the satellite. Generally, the main beams of the LMDS transmitters are not directed towards the satellite receivers and radiation towards the satellite is from the sidelobes of the antennas. The satellite receive antenna has a beam directed towards the earth, and within the resultant antenna footprint there are a number of LMDS cells. Because of the geo-stationary position of the satellite, the geometry remains fixed in this scenario. To successfully achieve co-frequency sharing, the aggregate interference power received at the satellite from all LMDS transmitters operating on a particular frequency must be below a value that in these calculations was specified as acceptable by the satellite system operator.

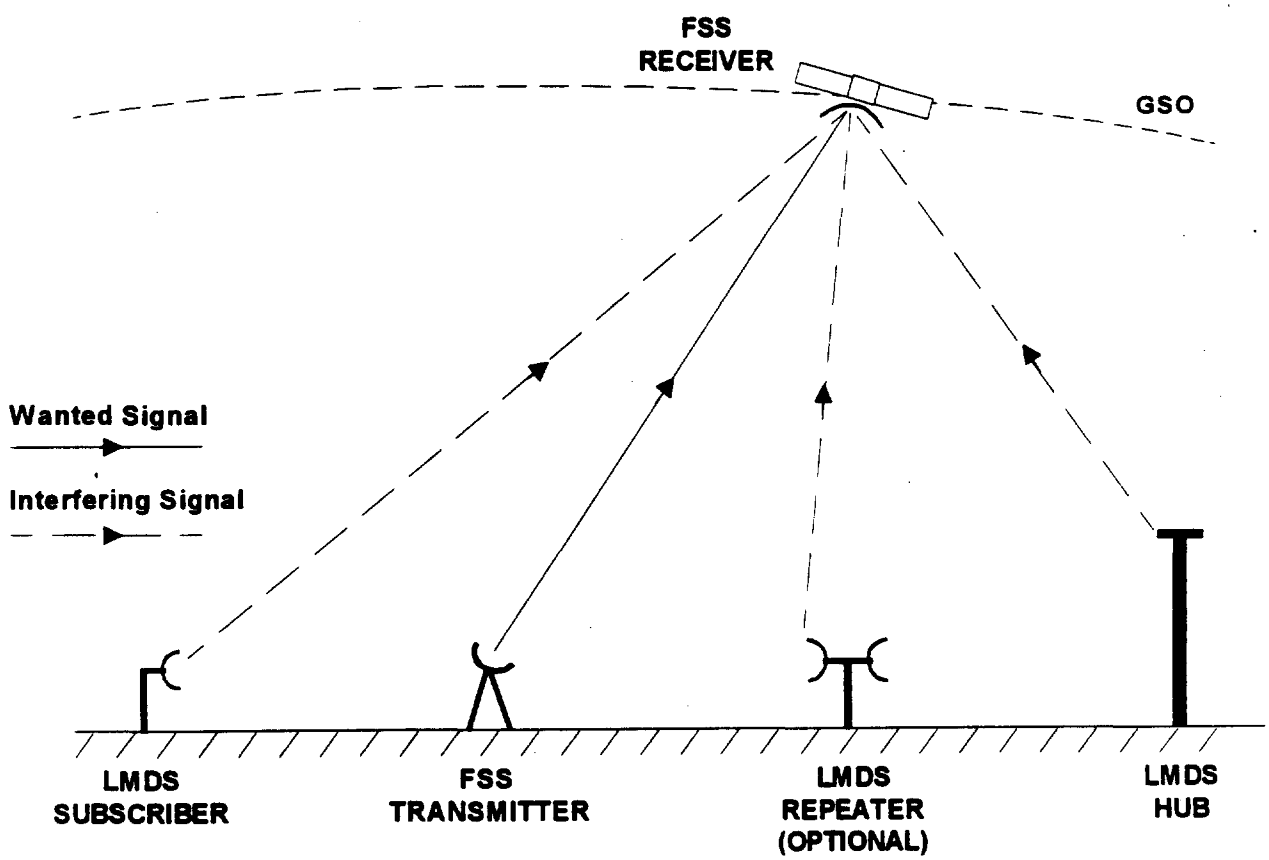

Figure 3.3-1 LMDS Transmitters (Hub, Subscriber Equipment, and Repeaters) Sending Interfering Signals Towards a Geostationary Orbit (GSO) Fixed Satellite Service (FSS) Receiver

3.4 LMDS Transmitters Interfering into FSS Non-Geostationary Orbit (NGSO) Satellite Receivers

The model for this scenario is shown in Figure 3.4-1. This scenario is similar to the prior scenario, but the geometry changes. The changing position of the NGSO satellite and the fixed pointing angles of the LMDS transmitters (relative to the horizon and in azimuth) determine the angular relationships between the LMDS main beam and the satellite. Successive satellites passing over the LMDS cells follow different arcs across the sky, which introduces further variation into the geometry of the model. The radiation towards the satellite occurs through the LMDS antenna sidelobes.

The satellite receive antenna has a beam directed towards the earth. The antenna footprint on the earth would typically cover a number of LMDS cells, each of which would replicate the scenario shown in Figure 3.4-1. To successfully achieve co-frequency sharing, the interference power received at the NGSO satellite from all LMDS transmitters operating on a particular frequency must be lower than a value that in these calculations was specified as acceptable by the NGSO FSS system operator.

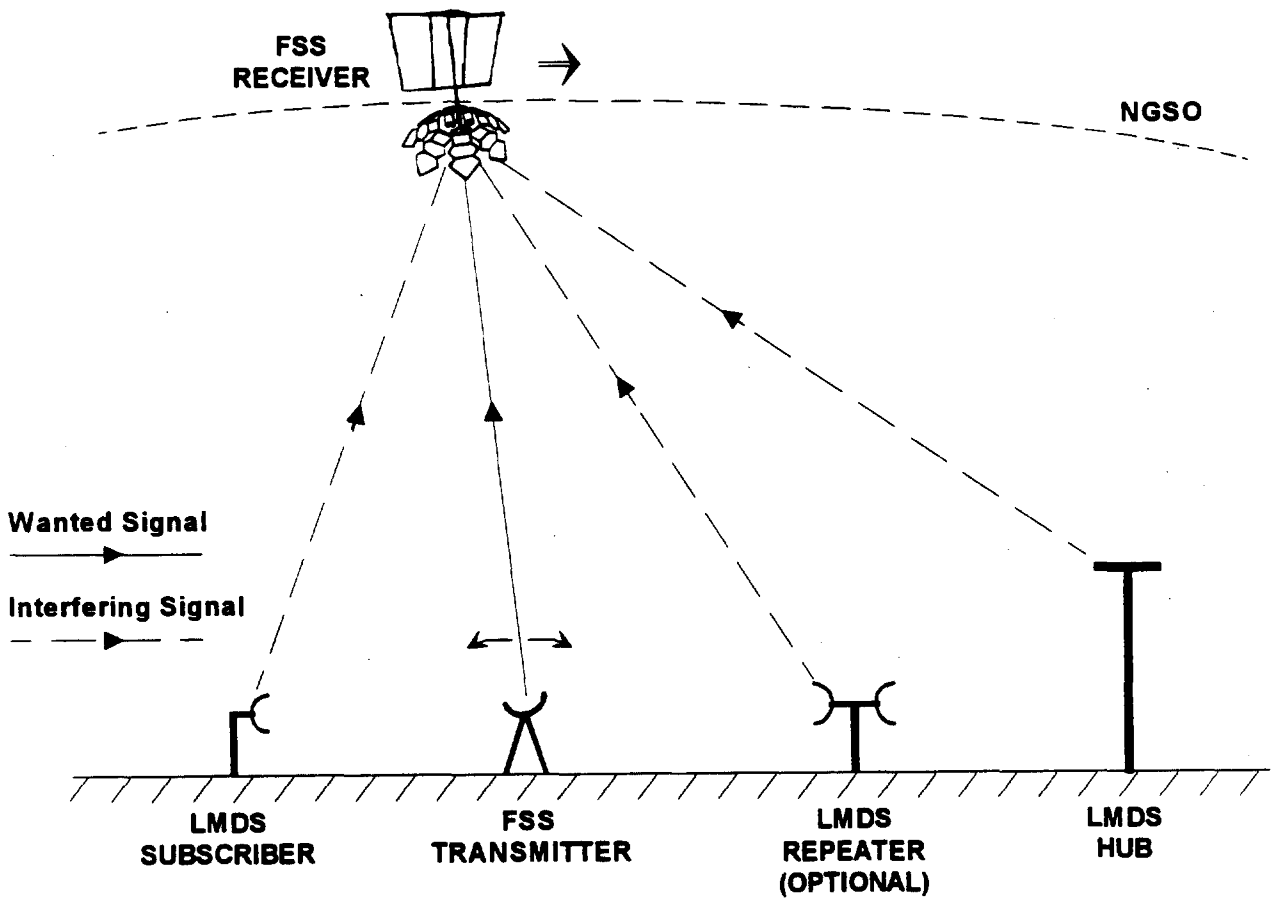

Figure 3.4-1 LMDS Transmitters (Hub, Subscriber, and Repeaters) Providing Interfering Signals to a Non-Geostationary Orbit (NGSO) Fixed Satellite Service (FSS) Receiver

3.5 Frequency Sharing Between FSS Satellite Downlink Beacons and LMDS Hub Stations and Subscriber Terminals in the Band 27.500 - 27.501 GHz

WARC-92 adopted RR882A which allocated the bands 27.500 - 27.501 GHz and 29.999 - 30.000 GHz on a primary basis for use by the Fixed Satellite Service (space-to-Earth) for power link control beacons. Similarly, WARC-92 also adopted RR882B which allocated the band 27.501 - 29.999 GHz on a secondary basis for FSS (space-to-Earth) for power link control beacons.[1] RR882A imposes limitations on the maximum equivalent isotropic radiated power in the direction of adjacent satellites as well as power flux-density limits on the Earth's surface.

Power control beacons may be used to dynamically compensate for attenuation due to rain on the satellite uplink path. The earth station estimates that the change in uplink attenuation based on the change in the power level of a space-to-Earth beacon signal in a frequency in or near the uplink frequency band. There is potential for interference from the FSS beacons into LMDS receivers, and the inverse case of potential interference from LMDS transmitters into the beacon receivers. These two scenarios are shown in Figure 3.5-1.

[1] The FCC has yet to act upon the WARC-92 provisions regarding RR882A and RR882B

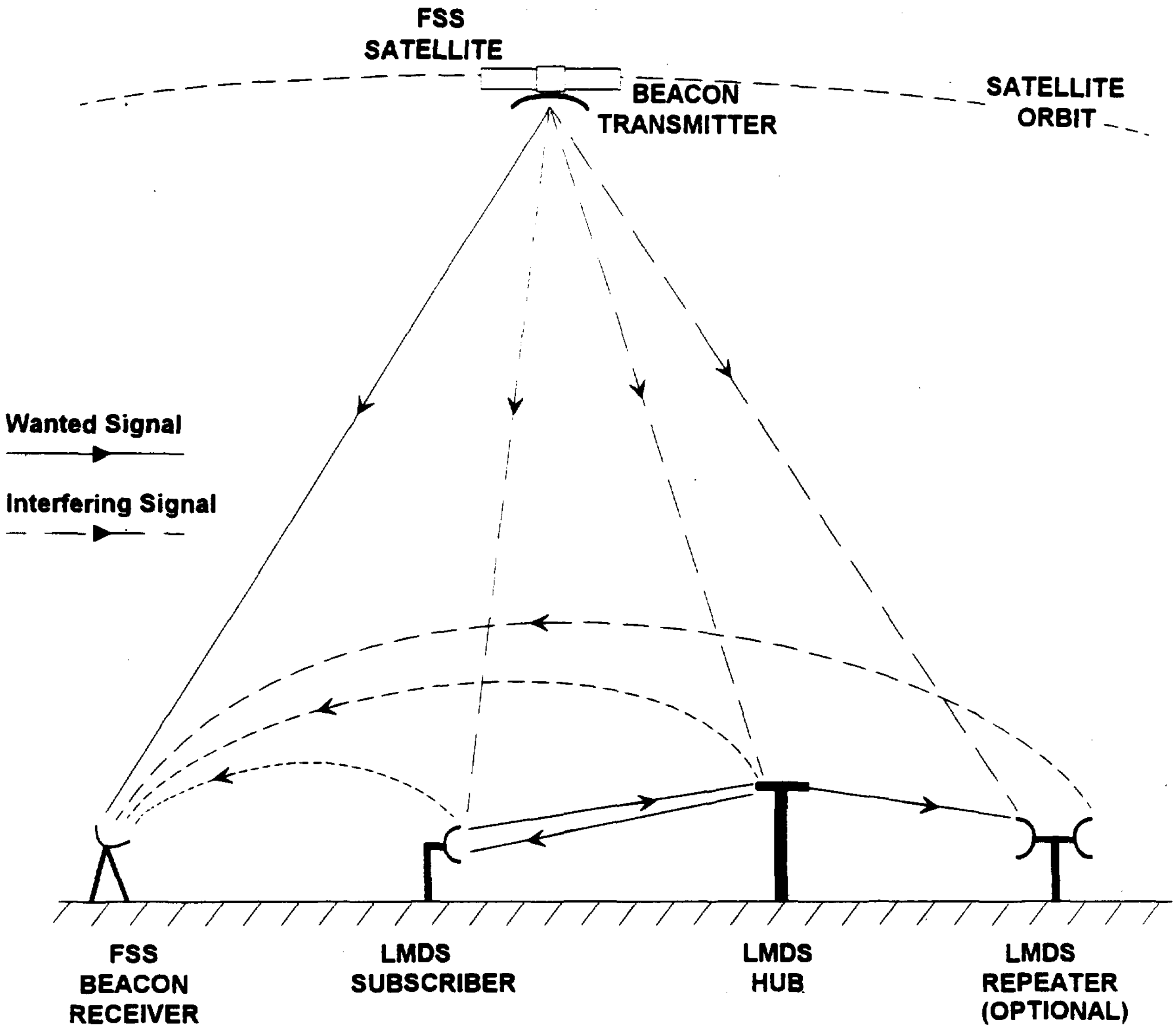

Figure 3.5-1 Sharing/Interference Scenario for FSS Beacon System and LMDS System (LMDS Sites are Both Transmit and Receive.)

4.0 Technical Analysis

4.1 Scope of Technical Analysis

A number of technical factors were considered for inclusion in the analysis of FSS earth stations interfering into LMDS receivers. The following table lists the technical factors considered and the assumptions used for those factors in the analysis. A more complete discussion appears in the Joint Technical SubGroup documents listed:

	Item	Modelling
JTSG Doc. No.	Foliage Attenuation	Include bounding cases using data from input document
4.1A	Rain Attenuation Crane Model	Do clear air case and rain case, with rain attenuation for both wanted and unwanted signal
	Power Control	As appropriate
	Depolarization	Ignore unless supported by data
	Path Blockage	Ignore unless supported by data
	Multipath	Additional cases if supplied
4.1B	Atmospheric Attenuation	Ignore
4.1C	Aggregation of Interferers	Single interferer plus one or more cases of multiple interferers
4.3	Off-Axis Polarization Discrimination	No isolation between linear and circular off-axis
4.4C	Impact of Interference Digital into Analog and Digital into Digital	
	Wideband	AWGN
	Narrowband	Use AWGN as lower bound, add power densities for upper bound
4.12	Sidelobe Discrimination	As specified by system proponent; also use ITU 699 pattern

Numerous potential interference cases were identified for possible analysis and are listed in the following table. Because of the vast number of potential cases, and based on the work of the Joint Technical SubGroup, only some of the potential cases were selected for evaluation. These cases are shown in boldface in the table below.

Class	Number of Cases	List of Cases
LMDS Proponent	3	**CellularVision/Suite 12** **VideoPhone** **Texas Instruments**
LMDS Modulation	3	**AM** **FM** **Digital**
LMDS Links	4	**Hub-to-Subscriber** **Subscriber-to-Hub** Repeater-to-Subscriber Intercell Backbone
FSS Earth Stations	5	**ACTS USAT** **ACTS High Bit Rate** **Hughes Spaceway/ACTS T1** **Teledesic Standard Terminal** **Teledesic GigaTerminal**
Foliage	4	**No foliage blockage** Foliage blocks wanted signal Foliage blocks unwanted signal Foliage blocks both wanted and unwanted signal
Rain	2	**Clear sky** **Rain attenuation for both signals**
Multiple Interferers	2	**Single interferer** **Multiple interferers**
Single Interferer Geometries	5	**Interferer located at transmitter** **Interferer located between receiver and transmitter** **Interferer in receiver main beam and located beyond transmitter** **Interferer at random location** Interferer and receiver at different altitudes
Antenna Pattern	2	**As supplied by proponent** ITU-R Recommendation 699-1

4.2 Methods of Interference Calculations for FSS Earth Stations Accessing GSO Satellites Interfering into LMDS Receivers

An FSS VSAT operating in the vicinity of an LMDS receiver may pose unacceptable interference levels to LMDS depending on the relative power levels, sidelobe discrimination and spatial separation between the two systems. The methodology employed here is to calculate a protection distance around the LMDS receiver based on the required protection criteria (i.e., allowed C/(N+I)).

The following parameters are used in this interference analysis:

LMDS

- Cell radius
- Receive antenna peak gain
- Receive antenna sidelobe pattern
- Transmitter EIRP per channel
- Signal bandwidth
- Receive system noise temperature
- Allowed single entry C/(N+I)

Satellite

- Transmit antenna peak gain
- Transmit antenna sidelobe pattern
- Signal bandwidth
- Transmitter power per channel
- Earth station elevation angle

System characteristics were provided by the various system proponents. Based on the required carrier-to-noise ratio and the system characteristics, the allowed space loss and thus separation distance is calculated as a function of antenna geometry. Note that this methodology contains a number of simplifying assumptions. In particular, a flat earth is assumed which, in certain cases, results in separation distances on the order of several tens of miles when the FSS transmitter is located in the main beam of the LMDS receiver. Depending of the height of the transmitter, these distances could be beyond the radio horizon. However, the effects of the earth's curvature is negligible for separations distances that are on the order of several LMDS cell diameters and the conclusions reached about interference levels within this area appear valid. Further, as recommended by the Joint Technical Sub-Group, blockage and scattering were not considered since models of these effects in an urban environment could not be agreed upon. Because of natural and/or man-made blockage and reflection effects, free space loss equations may not accurately reflect the magnitude of FSS interference into LMDS.

4.3 Methods of Interference Calculations for FSS Earth Stations Accessing NGSO Satellites Interfering into LMDS Receivers

In order to evaluate the impact of interference from different sources , the received power of the interfering signals that are within the bandwidth of the desired receiver should be calculated. For each interfering signal the following parameters should be identified.

1) Interferer transmit power in the direction of the intended receiver.
2) Interferer signal format such as FM, QPSK with rate 1/2 convolutional code, etc.
3) Receiver antenna gain in the direction of the interferer.
4) Interferer signal center frequency and bandwidth.
5) Interferer path loss including rain loss, atmospheric loss, foliage, and others. The assumptions used in calculating the interferer path loss should be consistent with the assumptions used in calculating the desired signal path loss.

Depending on the sharing scenario, the interference evaluation methods are different. In this section the methods proposed for calculating the interference in different sharing scenarios are described. In all interference calculations it shall be assumed that the interfering signals upon arrival at the victim receiver are noncoherent in both symbol timing and carrier phase.

Case 1: Digital signal interference to analog

1a: Wide signal band interference - If the bandwidth of the interfering signal is wider than the bandwidth of the desired signal, the Additive White Gaussian Noise (AWGN) assumption can be used. In this case the power density of all interference sources are added together to increase the background noise temperature. This method generally gives good estimate of the interference effect. If the number of interferers is large (say greater than 5) then AWGN assumption is a good approximation to the aggregate of average power of the composite interferers signal. If the number of interferers is relatively small (less than 6) or if the bandwidth of the interferers is about the same as the desired signal, then AWGN assumption cannot be viewed as a good approximation, but simulation can provide a more accurate answer.

1b: Narrow/Partial Band Interference - If the bandwidth of the interference sources only cover part of the desired signal band, then it is recommended to evaluate lower estimate (best case) and upper estimate (worst case) of the interference impact. Lower estimate can be calculated by adding the power of all the in-band interferers to the thermal noise. The upper estimate can be calculated by adding the power density of all interferers to the thermal noise. If the number of interference sources are large (say greater than 5) then the lower estimate calculation is a good estimate for calculating the impact of the interference.

If the lower estimate calculations indicate interference, then mitigating factors should be considered. if the upper estimate calculations does not indicate significant interference impact, then sharing in this scenario is possible. If the lower estimate calculations indicate significant interference impact, simulation technique should be used to calculate the impact of interference and to investigate mitigation strategies.

Case 2: Digital Signal Interference to Digital Signal

2a: Wide band signal interference - If the bandwidth of the interference source is at least three times larger than the bandwidth of the desired signal and their bandwidths overlap, then the AWGN assumption is a good estimate for calculating the impact of the interference. If the number of interferers is large (say greater than 5) then AWGN assumption is a good approximation to the statistics of the composite interferers signal. if the number of interferes is relatively small or if the bandwidth of the interferers is about the same as the desired signal, then AWGN cannot be viewed as a good approximation and simulation can provide a more accurate answer.

2b: Narrow band signal interference - If the bandwidth of the interference sources only cover part of the desired signal band, then it is recommended to evaluate lower estimate (best case) and upper estimate (worst case) interference power calculations. Lower estimate can be calculated by adding the power of all the in-band interferers to the thermal noise. The upper estimate can be calculated by adding the power density of all interferers to the thermal noise. If the number of interference sources are large (say greater than 5) then the lower estimate calculation is a good estimate for calculating the impact of the interference.

If the lower estimate calculations indicate interference then, mitigating factors should be considered. if the upper estimate calculations does not indicate significant interference impact, then sharing in this scenario is possible. If the lower estimate calculations indicate minimal interference impact and upper estimate calculations indicate significant interference impact, simulation technique should be used to calculate the impact of interference and investigating mitigation strategies.

Case 3: Analog Signals Interfere with Digital Signals

3a: Wide band signal interference - AWGN assumption provides good estimate for interference calculations. The in-band power of all interference sources should be added to the thermal noise.

3b: Narrow band signal interference - Lower estimate and upper estimate calculations can be performed similar to Case 1. If lower estimate and upper estimate calculations do not provide adequate results, simulation is recommended to evaluate the impact of interference and investigating mitigation factors.

4.4 Methods of Interference Calculations of LMDS into FSS Satellite Receivers

Interference calculations were made for two GSO and one NGSO FSS systems. It was determined that the worst-case interference scenario was where the FSS receiving antenna beam intersection with the Earth is at minimum elevation angle (LMDS transmitter antenna discrimination is minimum). The NGSO system operates with a minimum elevation angle of 40I using a unique beam area that remains fixed on the Earth's surface irrespective of the satellite motion. Because of this factor, the same calculation method was found to be applicable to both GSO and NGSO systems.

The FSS proponents specified the allowed aggregate interfering power spectral density at the respective satellite receivers.

LMDS proponents specified the maximum number of LMDS cells that could lie within each FSS antenna beamwidth intersection with the Earth for a minimum beam arrival angle of 30I above the horizontal, the maximum EIRP density of each transmitter within a cell, and the off-axis antenna gain discrimination mask for each LMDS transmitter. For the small Teledesic footprint, the number of LMDS cells was based on 100% geographic occupancy.

Two cases were considered: Cell hub-to-subscriber transmissions into FSS satellite receivers; cell subscriber-to-hub transmissions into FSS satellite receivers. For LMDS systems using power control to combat rain fade it was assumed that 10% of transmissions were under rain condition power levels, but this increase in power was not attenuated by rain in the direction of the satellite receiver.

The aggregate interfering power density at the satellite receiver was calculated using a simple spread sheet as follows (quantities in dB):

EIRP density of an average LMDS transmitter within one cell,
- antenna discrimination of an average LMDS transmitter toward the satellite,
+ 10 log of the maximum possible number of simultaneous co-channel transmissions within one cell, - basic transmission loss to the satellite,
+ peak satellite antenna gain,
+ 10 log number of LMDS cells contained within satellite antenna beamwidth.

A 3 dB polarization mismatch factor, peaking appropriate to the particular modulation, and a 3 dB interleaving factor was included. The calculated aggregate interference power density was compared with the allowed value to determine the margin against LMDS interference.

This simplified approach assumes that all LMDS transmitters are contained within the FSS uplink beamwidth. The accuracy of this simplified approach was compared with the more exact analysis afforded by the FCC computer program (document NRMC/21) which is capable of taking into account LMDS transmitters beyond the FSS mainbeam, well into the FSS sidelobes. The two methods generally agreed within about 1 dB for elevation angles above 15l when LMDS transmitters are not visible at lower elevation angles and for the Teledesic 40l minimum elevation angle cases. This situation pertains for FSS satellites located such that full CONUS coverage is possible. For a Pacific or Atlantic rim international satellite, LMDS transmitters in CONUS can be visible to an FSS satellite at elevation angles down to 0l. Document WG1/46 (Attachment I) investigates the impact of this effect upon interference margins.

The EIRP density of an average LMDS subscriber-to-hub transmission assumed a uniform subscriber density in a circular cell about a central hub. It was assumed that subscriber EIRP was adjusted for distance and rain loss to provide a fixed signal level at the hub receiver. Numerical integration was used to determine the average EIRP expected from a member of such a population.

The antenna discrimination of an average LMDS subscriber transmitter toward an FSS satellite assumed that any azimuthal pointing direction was equally likely. A computer program calculated pointing directions to the FSS satellite relative to the LMDS mainbeam direction, calculated off-axis gain from the LMDS antenna masks, and employed numerical integration to determine the average (statistically expected) value that would result from a large population.

The detailed spreadsheet calculations are contained in documents WG1/46 (hub-to-subscriber) and WG1/54 (subscriber-to-hub). These documents are duplicated in Attachments I & J and will not be repeated here.

4.5 Methods of Interference Calculations for other Scenarios

4.5.1 FSS Power Control Beacons (Downlink) in The 27.5 - 29.5 MHz Band

There is an international allocation for satellites to transmit a downlink power control beacon in a 1 MHz band centered about 27.5005 GHz. The ACTS satellite transmits such an unmodulated beacon at 27.505 GHz. Detailed computations are covered in Document WG1/88 contained in Attachment K.

There are two interference scenarios: The downlink beacon signal may cause interference to LMDS receivers; LMDS transmissions may interfer with FSS Earth stations receiving such a beacon.

For the case of interference to LMDS receivers, it was assumed that beacon interference power must be 6 dB below LMDS receiver thermal noise in a 1 MHz band. The allowed maximum LMDS off-axis antenna gain at a given elevation angle toward a satellite to meet this criteria was calculated. This value of gain was compared with LMDS values to determine if interference was likely.

For the case of LMDS transmissions causing interference to FSS Earth station reception of the beacon signal, it was assumed that an LMDS worst-case single interference entry must be 13 dB below the FSS Earth station thermal noise level. The free-space propagation distance necessary to insure this result was then calculated.

4.5.2 Effect of Diffuse Scattering Upon Interference to FSS Satellite Receivers

Since the majority of power radiated from an LMDS hub antenna is incident upon the Earth's surface, the effect of diffuse scattering should not be neglected. An extensive search was undertaken to determine levels that might be expected and no directly applicable data was found in the literature. Scattering coefficients in the range of -5 dB to -40 dB were noted for cases of diffuse scatter in the specular direction and for backscatter. Most measured data was for frequencies below 20 GHz. One study of scatter from buildings at 11.2 GHz indicated in the order of -7 dB in the specular direction and -30 dB at angles well removed from the specular (Prediction Models & Measurements of Microwave signals Scattered from Buildings, Al-Nuaimi & Ding, IEEE Trans. Antennas & Propagation, Vol. 42, No. 8, Aug 94).

A simplified model was used to illustrate the possible effect of diffuse scattering upon interference margins. It is assumed that the total LMDS transmitter power is incident upon the Earth, is reduced by the scattering coefficient, and is diffusely scattered equally in all directions above the horizontal. This results in an "apparent" minimum off-axis antenna gain 3 dB greater than the scattering coefficient.

For example, consider the effect of an assumed -30 dB scattering coefficient. An antenna in free space will have a specified off-axis gain envelope. When near the Earth and where the majority of the transmitted power is incident upon the Earth with a scattering coefficient of -30 dB, the simplified model yields a scattered power radiated in all directions above the horizon equivalent to a -30 + 3 = -27 dB(i) antenna gain based on the assumed value. From the viewpoint of a satellite, the antenna's effective off-axis gain mask is then limited to a minimum of -27 dB(i). Whenever an LMDS proponent's gain mask specifies an off-axis gain smaller than this value, diffuse scattering at this level would reduce the calculated margins based on the assumed value. Document WG1/46 (Attachment I) evaluates the margin reductions that would be expected for a particular case.

It should be noted that there is no hard evidence that such diffuse scattering actually occurs under the conditions of this report or should it occur, what level is to be expected. The above example serves to indicate that further investigation may be needed for hub antennas that claim very low sidelobe levels and do not take account of scattering effects.

5.0 Mitigating Factors and Opportunities

This chapter summarizes the mitigation opportunities investigated by the Mitigation Opportunities Ad Hoc Committee. Sections 5.1 through 5.8 each deal with a particular category of mitigation opportunity identified by the committee. Within each section, the papers submitted and reviewed by the participants are listed[1], the mitigation opportunity or opportunities are described, the feasibility is discussed, the economic impact is estimated, and the rule applicability is described. This chapter reflects the views expressed in the contributions and reviews submitted to the committee, and *do not represent a consensus of Working Group 1.* In addition to the mitigation opportunities identified by the committee, several NRMC documents that deal with mitigating factors are summarized here for completeness. Section 5.9 summarizes quantitative values for mitigation opportunities as presented in document NRMC/46. Section 5.10 provides a copy of mitigation opportunities outlined in document NRMC/52 which is the minutes of the full negotiated rule-making committee meeting on 9/6/94. Mitigation opportunities identified to be of general use in document NRMC/86 (WG1/67) are given in Section 5.11.

5.1 Blockage

5.1.1 Papers Submitted/Reviewed

MIT/1.1, 1.1R1 - Prediction Models and Measurements of Microwave Signals Scattered from Buildings
MIT/1.2 - Foliage Attenuation Model for Use in LMDS/FSS Sharing Analysis for WG1A
MIT/1.3, 1.3R1, 1.3R2 - Foliage Attenuation at 30 GHz
MIT/1.4 - Attenuation of Radio Signals by Foliage (JTSG/4.1)
MIT/1.5 - Path Loss Factors for 28 GHz LMDS-FSS Sharing Analysis (JTSG/4.1a)
MIT/1.6 - Path Loss Factors (JTSG/4.1c)
MIT/1.7 - Use of Computerized Mapping Tools in Developing and Evaluating Rules in Complicated Multi-Service Co-Frequency Sharing Scenarios

5.1.2 Description of Mitigation Opportunity

Building, foliage, and terrain blockage, and shielding/absorbing can be used to provide path loss between an interference source and a victim receiver in addition to the free space path loss that occurs with increasing distance. Application of such mitigation techniques would reduce the required separation between interference sources and victim receivers providing different services. Three-dimensional maps of urban areas may be used to facilitate the study of particular interference scenarios.

5.1.3 Feasibility Estimate

Building, foliage, and terrain blockage depend upon the specific geometry between interference sources and victim receivers. Shielding and absorbing may be applied to specific interference sources and/or victim receivers to reduce the amount of

[1] Submitted papers bear the designation "MIT" (for mitigation)/*x.y.* Reviews of these papers have the added designation "R*n*". The mitigation documents are collected in document NMRC-89 Rev.1, 10/23/94.

interference received on a case-by-case basis. Prediction of this interference may be feasible for locations where three-dimensional city maps are available. In addition to the interference shielding that buildings may provide, reflections from building surfaces may lead to increased interference and/or decreased site shielding in some situations. This technique may be quite useful in a situation where some form of co-ordination or operational mitigation techniques are required. For MSS feeder links, tree attenuation may be used to provide some low elevation angle shielding around the earth station. Pine trees have been suggested due to the non-seasonal nature of the obstruction.

5.1.4 Economic Impact

The economic impact is minimal when building, foliage, and terrain blockage exist naturally between terminals from different systems. The economic impact of shielding by trees around an MSS feeder link would likely be manageable as long as the minimal look angle to the satellite was not blocked. Construction of additional large structures to provide site shielding can have a much greater economic impact.

5.1.5 Rule Applicability

A rule could be constructed to allow for a decrease in the required separation distance between terminals from different systems when naturally occurring blockage is apparent. Specific formulas could be developed to quantify the effect and included in the rule. Alternately, rules could be written to provide for operational mitigation techniques that determine in real time whether interference occurs. A rule could be written to require the use of shielding and/or absorbing at the installation site of the system terminals.

5.2 Time Sharing

5.2.1 Papers Submitted/Reviewed

NONE

5.2.2 Description of Mitigation Opportunity

Two possible time-sharing mitigation opportunities were discussed. One is for analog modulation, and the other is for digital modulation. For analog FM modulation, certain types of bursty interference may be more tolerable than others due to FM improvement/discrimination of unwanted signals with low duty cycles. With digital modulation, coordinated time sharing such as time-division multiplexed signals could provide simultaneous use of the same frequency band by FSS and LMDS.

5.2.3 Feasibility Estimate

Analog FM likely provides an improvement on the order of several (<10) dB interference rejection when there is a frequency separation between the desired and interference carriers with greater improvement for larger carrier separations within the total signal bandwidth. Digital time sharing must overcome the difficulty of synchronizing transmissions from highly random locations.

5.2.4 Economic Impact
There is no additional economic impact for analog FM improvement for systems employing this type of modulation. The economic impact of digital time-sharing is proportional to the difficulty in solving the synchronization issue.

5.2.5 Rule Applicability
Time sharing could be employed as a technique to meet general rule provisions requiring system designs that would allow co-frequency sharing.

5.3 Antenna Improvements

5.3.1 Papers Submitted/Reviewed
MIT/3.1, 3.1R1, 3.1R2 - Interference Rejection Using Sidelobe Canceller, FCC Working Paper
MIT/3.2 - Reference LMDS Subscriber Antenna Pattern for Use in Interference Assessment (WG1/41)
MIT/3.3 - Prospects for Side Lobe Discrimination for LMDS Receivers and Transmitters (JTSG/ 4.12)
MIT/3.4 - The Practicality of Sidelobe Control for Satellite Earth Terminal Antennas (JTSG/ 4.13)

5.3.2 Description of Mitigation Opportunity
Two different types of antenna improvements are covered under this mitigation opportunity. The first is the use of active antenna arrays to place a pattern null in the direction of a detected interference signal. The second opportunity is to require improved sidelobe control over current antenna designs.

5.3.3 Feasibility Estimate
Active antenna arrays and sidelobe cancellers are feasible, but can be quite complex, and require a significant amount of front-end RF hardware. Active sidelobe cancellation does not decrease the amount of interference received through main beam coupling. Improved sidelobe control on fixed antennas, may also be possible, with the feasibility inversely proportional to the amount of additional sidelobe suppression. Factors such as scattering from antenna mounts and other surrounding objects may limit the amount of sidelobe suppression that can be easily achieved. Mechanical tolerances on antenna elements directly impact the achievable sidelobe suppression of fixed phased array antennas.

5.3.4 Economic Impact
The economic impact of sidelobe cancellers and active antenna arrays is proportional to the complexity and additional amount of RF hardware. The economic impact of improved sidelobe control is proportional to the amount of sidelobe suppression required. It was suggested that backlobe suppression through use of absorbing material and/or moderate shielding will result in more costly uplink terminals and installation costs while backlobe suppression should be more cost effective to

implement than significant frontal lobe suppression.

5.3.5 Rule Applicability

A rule could be formulated requiring that antenna sidelobes (LMDS and/or FSS) fall below those of a specific antenna mask that specifies the amount of sidelobe control required. This technique could be used by a proponent to meet sharing requirements where more economic choices produce insufficient results.

5.4 Band Sharing

5.4.1 Papers Submitted/Reviewed

MIT/4.1, 4.1R1 - Interference Mitigation Opportunity Through Re-Location of LMDS Hub Stations
MIT/4.2 - LMDS Hub Diversity Analysis

5.4.2 Description of Mitigation Opportunity

Locating LMDS hub stations on the southern edge of the LMDS cell with directional hub antennas could reduce the effect of interference into LMDS subscriber terminals, caused by FSS uplinks to geosynchronous satellites. Use of unidirectional hub antennas can compensate for increased propagation losses on the desired LMDS signal path, allowing cell sizes to be maintained compared to central hub configurations. Use of absorbing material/shielding to reduce backlobe emissions of FSS transmit antennas further improves opportunities for sharing when combined with this mitigation opportunity.
Hub diversity can be used when LMDS hubs are located close enough to each other so that nominal coverage areas overlap. When coverage areas overlap, subscriber terminals have the opportunity to point their narrow main beam in a different direction when unacceptable interference is received from a particular direction.
Mitigation opportunities such as channel plan coordination, partial use, geographic separation, and frequency-agile sharing were also mentioned, but no contributions were submitted.

5.4.3 Feasibility Estimate

Simulation results indicate that southern-edge located hubs can provide some interference mitigation for clear sky operation. Under moderate to heavy rain, the interference from FSS uplinks is greater than an omni-directional hub configuration. This occurs because the maximum path length on the hub to subscriber path is longer, and the desired signal suffers increased rain attenuation. Low rain loss regions could potentially benefit from the technique by using moderate power control. The impact on interference to satellite receivers from an increased number of subscriber terminals pointing toward the GSO satellite needs further investigation. This impact may be reduced since hub transmitters would now be pointed away from the GSO satellite. Although most subscriber antennas would be pointed generally in the southern sector, few may be expected to be pointed with boresights aligned with the satellite receiving antenna.

A "quick-look" analysis of hub diversity shows that this technique may offer substantial reduction in interference levels in unblocked environments. Implementation of hub diversity would require the buildout of an increased number of hub stations per unit area. This would impact the amount of aggregate interference into satellite receivers.

5.4.4 Economic Impact

The economic impact of implementing southerly located hubs, could be relatively low since LMDS cell sizes are maintained requiring no additional hub stations. Power control at the hub stations may require higher power transmitters with the economic impact depending on how close the maximum power is to the state-of-the-art maximum. Implementation of hub diversity would increase the cost of fixed infrastructure for an LMDS system relative to a system that does not employ hub diversity.

5.4.5 Rule Applicability

While southerly located hub stations do not result in a general sharing solution, a rule could be generated requiring or providing incentive for implementation of such an architecture in low rain rate regions of the country. A rule could be written requiring or providing incentive for the use of hub diversity by specifying maximum hub spacing between adjacent hubs in a contiguous service area.

5.5 Power/Bandwidth Adjustments

5.5.1 Papers Submitted/Reviewed

MIT/5.1, 5.1R1 - Non-Linear Interference Rejection
MIT/5.2, 5.2R1 (NRMC/68.1), 5.2R1 (addendum 1), 5.2R1 (addendum 2), 5.2R2 - Use of Power Margin as a Mitigation Opportunity Against Potential Interference from LMDS to Satellite Uplinks
MIT/5.3 - Increased Interference Tolerance Through Increased Transmitter Power

5.5.2 Description of Mitigation Opportunity

This mitigation opportunity exploits the non-linear nature of acceptable C/I as a function of C/N for a constant C/(N+I) at a receiver, assuming that noise and interference affect receiver performance equally. This mitigation opportunity suggests increasing the transmitter power in the system being interfered with. By increasing the transmitter power of a noise limited system by a small amount (<3 dB), the amount of interference that can be tolerated at the receiver is increased by a much larger amount (~10 dB).

5.5.3 Feasibility Estimate

Satellite uplinks are often noise limited due to the amount of transmitter power required to overcome path loss over large distances. Under this condition, very little margin is left for interference. Increasing the transmitter power of satellite uplinks is difficult when the required uplink power is close to the state-of-the art limit. An alternative to increasing maximum transmitter power is to reduce the amount of power control allocated to overcome rain fades. This leads to a decrease in system availability which may not be acceptable depending upon system service objectives. An increase in satellite uplink power creates additional interference into LMDS receivers. LMDS systems are typically self-interference limited and not noise limited. Hence, an increase in transmitter power does not lead to a comparable increase in the amount of interference power that can be tolerated in LMDS systems. Opposing views were submitted on the feasibility of increased power on satellite uplinks.

5.5.4 Economic Impact

The economic impact of increased transmitter power depends on how close the designed transmitter power is to the state-of-the-art maximum. If the designed transmitter power is well below the currently achievable maximum, then an increase in transmitter power is not very expensive. If the designed transmitter power is already relatively high, this increase could be costly if applied to a large number of terminals. Reduced system availability, and the resultant deterioration of service, lead to a reduced ability to charge for service. The magnitude of the reduction in system availability is related to the available excess margin and the rain rate statistics in the region where the earth station is located.

5.5.5 Rule Applicability

A rule could be constructed that would protect satellite receivers from a fixed amount of interference power from LMDS transmissions. Depending upon the threshold power level, different satellite systems may or may not require either increased transmit power (or decreased availability) as determined by system design.

5.6 Signal Processing

5.6.1 Papers Submitted/Reviewed

MIT/6.1 - Experiment to Determine Effect of Burst Mode QPSK Interference on FM Video
MIT/6.2, 6.2R1 - Interference Mitigation Techniques: Forward Error Control
MIT/6.3, 6.3R1 - In-House Testing of Continuous Look Through (COLT) Filter
MIT/6.4, 6.4R1 - Mitigation Technique for Wide Band Interference
MIT/6.5 - GNSS Interference Mitigation Techniques

5.6.2 Description of Mitigation Opportunity

Several types of mitigation opportunities are covered in this section. One method is the use of forward error control (FEC) on digital links to reduce the required carrier-to-noise plus interference ratio. FEC allows for decreased power margins at the expense of either throughput or bandwidth. An advanced interference mitigation technique is the use of non-linear interference rejection techniques. These techniques use powerful signal processing algorithms that exploit the spectral correlation properties of both the desired signal and the interference signal to increase the interference levels that can be received without degrading system performance.

5.6.3 Feasibility Estimate
Different rates of Forward Error Correction can be incorporated into digital system designs. Implementation of FEC leads to decreased throughput and/or increased required bandwidth. Interference rejection techniques show promise for future implementation, however, the amount of improvement for the particular case of (a small number of) FSS transmitters into LMDS receivers requires additional research. In addition, these techniques are generally designed to cancel a few dominant interference signals that are each detectable above the receiver noise floor, but are not applicable for interference from LMDS into FSS satellite receivers where the total interference is an aggregate of many interference sources, and the total interference power is below the noise floor (I/N<0 dB).

5.6.4 Economic Impact
The economic impact of different FEC coding rates is system-dependent, and results in trade-offs between power and bandwidth. Interference rejection techniques may become economically viable when mass produced. However, these techniques are not ready for immediate deployment because a significant amount of research is required to fully assess the applicability of these techniques to LMDS/FSS co-frequency sharing.

5.6.5 Rule Applicability
Signal processing could be employed as a technique to meet general rule provisions requiring system designs that would allow co-frequency sharing.

5.7 Coordination

5.7.1 Papers Submitted/Reviewed
MIT/7.1 - Operational Application of Interference Mitigation Techniques (WG1/61)
MIT/7.2 - Potential Field Testing Plan (WG1/72)

5.7.2 Description of Mitigation Opportunity
This mitigation opportunity utilizes real-time electronic communication between FSS and LMDS system operators to insure that interference is not caused. This opportunity works on the premise that both services are co-primary within the frequency band, and that the _first-in" principle would be used on a station-by-station basis. That is, new FSS transmitters locating in an LMDS area would be required to avoid causing interference, and new LMDS terminals operating in an area where an FSS earth station has already been established would be required to accept any interference from that earth station. Different possibilities for accomplishing this goal and still providing an acceptable grade of service include preclusion of FSS transmissions on frequencies in use by LMDS at a given time, and active avoidance by an LMDS system of frequencies in use by an FSS uplink at a given time.
Mitigation opportunities also identified by the committee include testing of new FSS/LMDS subscriber units, coordination mechanization, geographic separation, and active coordination.

5.7.3 Feasibility Estimate
This mitigation opportunity requires a real-time communication link between the LMDS and FSS systems. Further study is required to determine the feasibility of such a system.

5.7.4 Economic Impact
The economic impact is directly related to the change in system complexity in both the LMDS and FSS systems. This burden would be determined by the shared by LMDS and FSS systems, although perhaps disproportionately.

5.7.5 Rule Applicability
A rule could be written requiring active coordination between LMDS and FSS services in a given geographic service area should an appropriate system be designed.

5.8 Coherent Synchronous Receivers

5.8.1 Papers Submitted/Reviewed
NONE
5.8.2 Description of Mitigation Opportunity
No description of this mitigation opportunity was provided.
5.8.3 Feasibility Estimate
NONE
5.8.4 Economic Impact
NONE
5.8.5 Rule Applicability
NONE
5.9 Quantitative Mitigation Opportunities in NRMC/46 (TI presentation)
The following quantitative values for mitigation opportunities were proposed in document NRMC/46, and are included in this report to provide a complete summary of the mitigation opportunities mentioned during this negotiated rule-making proceeding.

Increase 5 degree elevation angle to
- 10 degrees -> 7 dB
- 15 degrees -> 11 dB
- 20 degrees -> 15 dB

Reduce maximum terminal power -> 3 to 6 dB
Increase separation distance from 1 km
- to 2 -> 6 dB
- to 10 km -> 20 dB

Blockage
- berms -> 40 dB
- structures -> 10 to 40 dB
- trees -> 15 to 40 dB

Reduced cell radius -> 10 dB

It is recognized that the full mitigation factor may not necessarily be realized when several mitigation factors are implemented simultaneously.

5.10 Mitigation Opportunities in NRMC/52 (Minutes of Full Committee Meeting 9/6/94)

The following mitigation opportunities were mentioned in the full NRMC meeting on 9/6/94, and are included in this report to provide a complete summary of the mitigation opportunities mentioned during this negotiated rule-making proceeding.

1.) requiring a specific depression angle for LMDS hub stations, i.e.:
    a.) maximum allowable hub antenna main beam null angle above the horizon
    b.) minimum hub antenna main beam depression angle
    c.) maximum allowable hub antenna sidelobe levels
    d.) improved customer premise antenna performance standards
2.) require maximum EIRP density from hubs and subscriber terminals
3.) constrain subscriber terminals geographically or in frequency
4.) limit satellite design parameters, i.e.:
    a.) constrain maximum allowable power flux density levels into earth stations
    b.) increase maximum power density levels into Earth stations,
    c.) limit or remove protection for non-geostationary satellite service if satellite antenna half-power beamwidth illuminates the Earth_s horizon
    d.) consider minimum allowable Earth station elevation angles below which satellite services must accept interference
    e.) specify minimum earth station antenna performance standards
5.) determine that new services (satellite and terrestrial) must accept more interference
6.) eliminate certain modulation parameter types that are not major business considerations but which could improve sharing
7.) choose sites for gateways for MSS feeder links and FSS services geographically removed from major metropolitan areas
8.) minimize the number of gateways consistent with providing a suitable service
9.) consider Earth station shielding at low elevation angles to the horizon (gateways)
10.) consider site shielding for LMDS transmitters and/or subscriber receiver locations
11.) consider interference cancellation technologies
12.) consider hub-density requirements in each metropolitan area
13.) reduce satellite footprint size
14.) require utilizing satellite tracking antennas or improve satellite pointing accuracy
15.) consider some band segmentation
16.) make spectrum assignment allocations to either the LMDS or FSS service based on system efficiency and public benefit of a particular service
17.) require digital modulation or digital compression techniques
18.) reduce bandwidth allocated to LMDS and/or satellite users
19.) require detailed frequency coordination between satellite proponents and LMDS in certain locations
20.) require that FSS monitor transmissions before it transmits
21.) require polarization discrimination
22.) require that a database of LMDS subscribers be maintained to assist in co-